Testicular Volume Measurement: Comparison of Ultrasonography, Orchidometry, and Water Displacement

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OBJECTIVES To determine the accuracy of orchidometry and ultrasonography for measuring the testicular volume by comparing the resultant measurements with the actual testicular volume in humans.

METHODS The testicular volume of 40 testes from 20 patients with prostate cancer (mean age ± SD 74.5 ± 7.5 years) was measured using the Prader orchidometer and ultrasonography before therapeutic bilateral orchiectomy. The ultrasound measurements of testicular volume were calculated using three formulas: length (L) × width (W) × height (H) × 0.52, L × W^2 × 0.52, and L × W × H × 0.71. The actual testicular volumes were determined by water displacement of the surgical specimen.

RESULTS The mean actual testicular volume of the 40 testes was 9.3 cm^3 (range 2.5 to 23.0). A strong correlation was found between the testicular volume calculated by the three ultrasound formulas and the actual volume (r = 0.910 to 0.965, P <0.0001) and was stronger than the correlation with the Prader orchidometer (r = 0.818, P <0.0001). The smallest mean difference from the actual testicular volume was observed with the formula L × W × H × 0.71, which overestimated the actual volume by 0.80 cm^3 (7.42%). The measurements using the Prader orchidometer correlated with the actual testicular volume and with the testicular volume calculated using the three ultrasound formulas (r = 0.801 to 0.816, P <0.0001). However, the orchidometer measurements had the largest mean difference from the actual testicular volume (6.68 cm^3, 81.7%).

CONCLUSIONS The results of this study have shown that measuring the testicular volume by ultrasonography is more accurate than by the Prader orchidometer, and the formula L × W × H × 0.71 was the most accurate for calculating the testicular volume. UROLOGY 69: 152–157, 2007.

Because the seminiferous tubules compromise 70% to 80% of the testicular mass, the testicular volume is believed to be an index of spermatogenesis.[1] Therefore, accurate testicular volume measurement is one way to assess testicular function. In infertile men, the testicular volume has correlated with the semen profiles.[2–5] In puberty and adolescence, testicular volume measurement is used to monitor pubertal status and assess the clinical significance of varicocele.[6–9] Currently, a number of measurement methods are used, including calipers, orchidometry, and ultrasonography (US). The testicular volume has traditionally been obtained using instruments such the Prader or punched-out orchidometer.[10,11] US is generally recognized as the most accurate method, as determined by comparison with the actual volume.[3,12–14] However, previous studies have shown a large variability in estimates by US depending on the formula used to calculate the testicular volume.[3,4,7,13–20] One recent study found that the most accurate formula to estimate the volume of canine testes was the length (L) × width (W) × height (H) × 0.71.[12] However, no consensus has been reached as to the best formula in humans.

This study determined the accuracy of the Prader orchidometer and US for measuring the testicular volume by comparing the results with the actual testicular volume of surgical specimens obtained from patients with prostate cancer. We also directly compared the testicular volume measurements between US and the Prader orchidometer.

MATERIAL AND METHODS

A total of 40 testes from 20 patients with prostate cancer scheduled for bilateral orchiectomy (mean age ± SD 74.5 ± 7.5

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years) were studied. After the patients provided written informed consent, the testicular volumes were measured preoperatively using a Prader orchidometer and US. The actual testicular volumes were measured by water displacement at orchiectomy.

The scrotal contents were palpated with the patient in the supine position, and the testicular volumes were determined by comparison with the testis models of a Prader orchidometer, which consists of 12 solid ellipsoid models ranging in volume from 1 to 25 cm^3 (1 to 6, 8, 10, 12, 15, 20, and 25 cm^3). All measurements were performed by one experienced urologist after stretching the scrotal skin over the testis in a warm room.[10]

High-frequency US using 5-MHz and 7.5-MHz transducers (ALOKA SSD2000, Tokyo, Japan) was performed with the patient in the supine position by one experienced examiner. The testes were scanned by using light pressure to avoid distorting the testicular shape, and gray-scale images of the testes were obtained in the transverse and longitudinal planes. At least three separate transverse and longitudinal images of each testis were recorded, and the testicular length, width, and height were measured using electronic calipers without the inclusion of the epididymis. The largest measurement in each testicular dimension was used for volume calculation and statistical analysis. The testicular volumes were calculated using three formulas: (a) the formula for a prolate ellipsoid: length (L) × width (W) × height (H) × 0.52 (LWH0.52)[3,4,7,12]; (b) the formula for a prolate spheroid: L × W^2 × 0.52 ($LW^2$0.52)[12–14,18,20]; and (c) the empiric formula of Lambert: L × W × H × 0.71 (LWH0.71).[12,15–17,19]

Bilateral orchiectomies were performed under local or spinal anesthesia, and the epididymides were removed. Each testis was weighed, and the actual testicular volume was measured by water displacement.

The testicular volumes measured using a Prader orchidometer and calculated using each of the three US formulas were compared with the actual testicular volume and with each other, and the correlation coefficients were calculated. The results are reported as the mean ± SD. Analysis of variance followed by Fisher's exact test was used for comparison of continuous variables. P <0.05 was considered significant.

RESULTS

The mean actual testicular volume and weight was 9.3 ± 4.5 cm^3 (range 2.5 to 23.0) and 9.5 ± 4.6 g (range 2.4 to 23.6). The US testicular volume measurements using each of the three formulas were different from the measurements using the Prader orchidometer (Table 1). The mean difference was −8.58 cm^3 (−54.43%) for the formula LWH0.52, −10.03 cm^3 (−64.1%) for the formula $LW^2$0.52, and −5.89 cm^3 (−37.78%) for LWH0.71. However, the testicular volume measurements obtained using each of the three formulas correlated strongly with the Prader orchidometer volume (Table 1 and Fig. 1).

The testicular volume measured using the Prader orchidometer and each of the three US formulas differed from the actual testicular volume (Table 2). The largest mean difference from the actual testicular volume was with the Prader orchidometer, which overestimated the actual volume by 6.68 cm^3 (81.7%). The

Table 1. Testicular volume measured by Prader orchidometer and ultrasonography

Measurement Method	Testicular Volume* (cm^3)	Difference from Prader Orchidometer† (cm^3)	Percentage Difference‡	Correlation Coefficient (r)§	P Value‖
POM	15.9 ± 6.1 (5.0 to 25.0)				
US					
LWH0.52	7.37 ± 3.85 (1.63 to 18.62)	−8.58 ± 3.74 (−16.09 to −2.64)	−54.43 ± 11.72 (−45.6 to 0.63)	0.816	<0.0001
$LW^2$0.52	5.92 ± 3.41 (1.32 to 16.28)	−10.03 ± 3.98 (−17.42 to −3.38)	−64.10 ± 12.01 (−83.45 to −32.03)	0.801	<0.0001
LWH0.71	10.06 ± 5.26 (2.23 to 25.42)	−5.89 ± 3.56 (−13.93 to 0.42)	−37.78 ± 16.0 (−68.19 to 1.67)	0.816	<0.0001

POM = Prader orchidometer; LWH0.52 = length (L) × width (W) × height (H) × 0.52; $LW^2$0.52 = L × W2 × 0.52; LWH0.71 = L × W × H × 0.71; ANOVA = analysis of variance; US = ultrasound. Data in parentheses are ranges.

* ANOVA P <0.0001 (POM vs. LWH0.52, POM vs. LWH0.71, POM vs. $LW^2$0.52, P <0.0001; LWH0.52 vs. LWH0.71, P = 0.013; LWH0.52 vs. $LW^2$0.52, P = 0.1771; LWH0.71 vs. $LW^2$0.52, P = 0.0002).

† ANOVA P <0.0001 (LWH0.52 vs. LWH0.71, P = 0.1131; LWH0.52 vs. $LW^2$0.52, LWH0.71 vs. $LW^2$0.52, P <0.0001).

‡ ANOVA P <0.0001 (LWH0.52 vs. $LW^2$0.52, P = 0.0016; LWH0.52 vs. LWH0.71, LWH0.71 vs. $LW^2$0.52, P <0.0001); percentage difference, % = (testicular volume by each formula − testicular volume by orchidometer) × 100/testicular volume by orchidometer.

§ Correlation coefficient between US testicular volume by each formula and Prader orchidometer.

‖ P value of correlation between US testicular volume by each formula and Prader orchidometer.

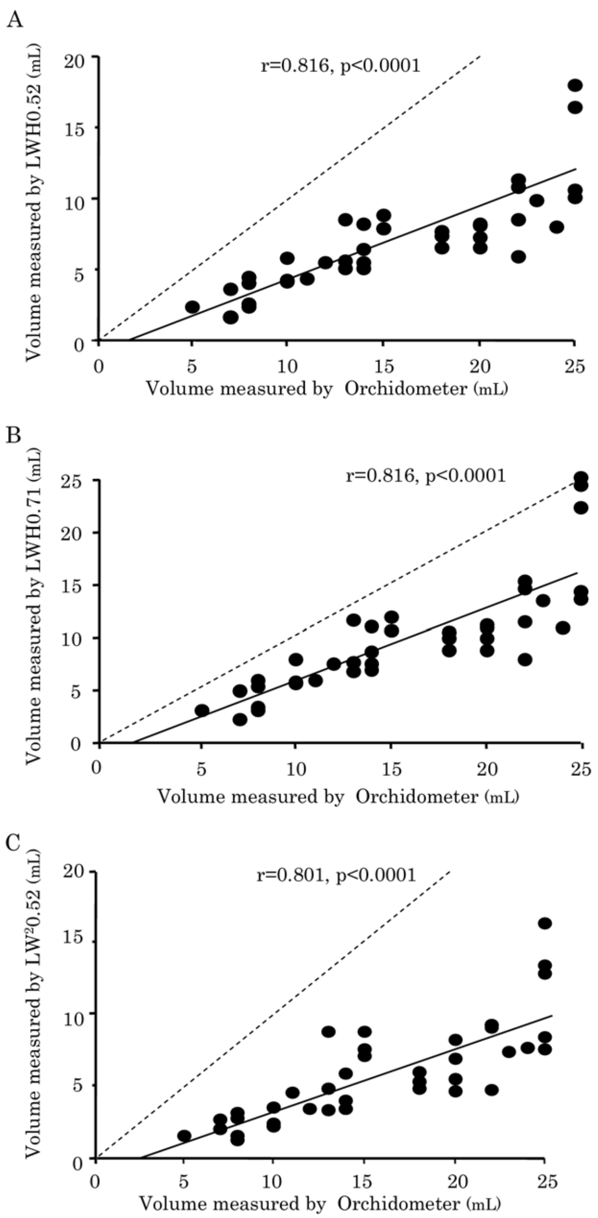

Figure 1. Correlations between testicular volumes measured by Prader orchidometer and US using **(A)** formula volume = L × W × H × 0.52, **(B)** formula volume = L × W × H × 0.71, **(C)** formula volume = L × W^2 × 0.52.

ultrasound formula $LW^2$0.52 underestimated the actual volume by 3.35 cm^3 (37.6%), LWH0.52 underestimated the actual volume by 1.90 cm^3 (21.3%), and LWH0.71 overestimated the actual volume by 0.80 cm^3 (7.42%). The US volume measurements using each of the three formulas showed a stronger correlation with the actual volume than did the Prader orchidometer (Table 2 and Fig. 2). The testicular volumes calculated using the formulas LWH0.52 and LWH0.71 had stronger correlations with the actual volumes than did those calculated using $LW^2$0.52. However, the Prader orchidometer measurements also correlated strongly with the actual testicular volume (r = 0.818, P <0.0001).

Table 2. Accuracy of testicular volume measured by ultrasonography and Prader orchidometer

Measurement Method	Testicular Volume* (cm^3)	Difference from Actual Volume† (cm^3)	Percentage Difference‡	Correlation Coefficient (r)§	P Value‖
Actual volume¶	9.27 ± 4.45 (2.5 to 23.0)				
POM	15.9 ± 6.1 (5.0 to 25.0)	6.68 ± 3.58 (1.1 to 15.0)	81.7 ± 44.8 (8.7 to 214.3)	0.818	<0.0001
Ultrasound					
LWH × 0.52	7.37 ± 3.85 (1.63 to 18.62)	−1.90 ± 1.24 (−4.97 to 0.12)	−21.3 ± 10.8 (−45.6 to 0.63)	0.965	<0.0001
LW^2 × 0.52	5.92 ± 3.41 (1.32 to 16.28)	−3.35 ± 1.95 (−8.19 to 0.03)	−37.6 ± 16.9 (−66.0 to 0.35)	0.910	<0.0001
LWH × 0.71	10.06 ± 5.26 (2.23 to 25.42)	0.80 ± 1.51 (−1.52 to 6.92)	7.42 ± 14.70 (−25.78 to 37.40)	0.965	<0.0001

Abbreviations as in Table 1.
Data in parentheses are ranges.
* ANOVA P <0.0001 (POM vs. LWH0.52, POM vs. LWH0.71, POM vs. $LW^2$0.52, POM vs. actual volume, P <0.0001; LWH0.52 vs. LWH0.71, P = 0.0116, LWH0.52 vs. $LW^2$0.52, P = 0.1707; LWH0.52 vs. actual volume, P = 0.074; LWH0.71 vs. $LW^2$0.52, P = 0.0001; LWH0.71 vs. actual volume, P = 0.4522; $LW^2$0.52 vs. actual volume, P = 0.0018).
† ANOVA P <0.0001 (POM vs. LWH0.52, POM vs. LWH0.71, POM vs. $LW^2$0.52, LWH0.52 vs. LWH0.71, LWH0.71 vs. $LW^2$0.52, P <0.0001; LWH0.52 vs. $LW^2$0.52, P = 0.0046).
‡ ANOVA P <0.0001 (POM vs. LWH0.52, POM vs. LWH0.71, POM vs. $LW^2$0.52, LWH0.52 vs. LWH0.71, LWH0.71 vs. $LW^2$0.52, P <0.0001; LWH0.52 vs. $LW^2$0.52, P = 0.0051); percentage difference, % = (testicular volume by each method − actual testicular volume) × 100/actual testicular volume.
§ Correlation coefficient between testicular volume by each measurement method and actual testicular volume.
‖ P value of correlation between testicular volume by each measurement method and actual testicular volume.
¶ Actual testicular volume determined by water displacement.

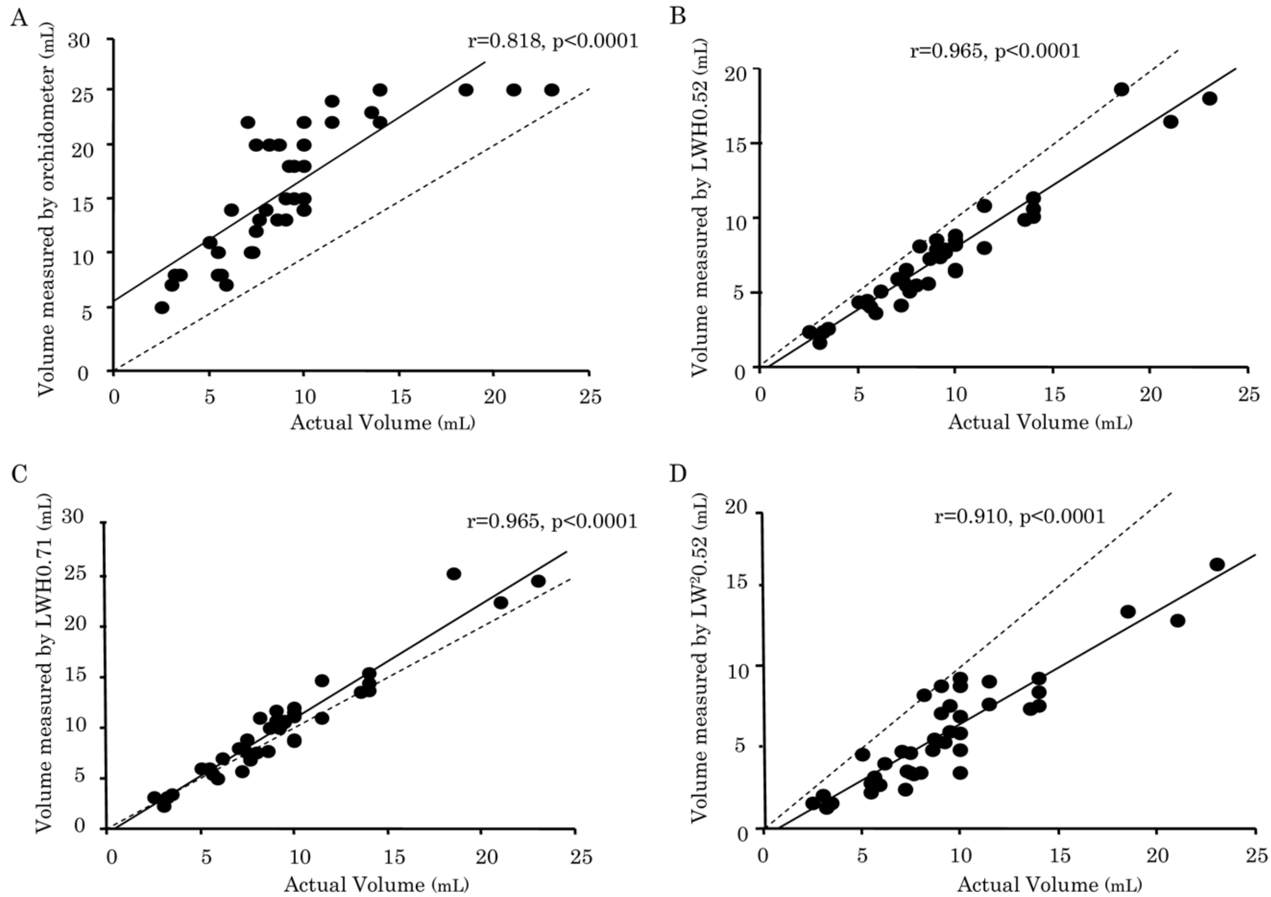

Figure 2. Correlations between actual testicular volumes and testicular volumes measured by Prader orchidometer and US. **(A)** Correlation between testicular volumes measured by Prader orchidometer and actual testicular volumes. **(B)** Correlation between testicular volumes measured by US using formula volume = L × W × H × 0.52 and actual testicular volume. **(C)** Correlation between testicular volumes measured by US using formula volume = L × W × H × 0.71 and actual testicular volume. **(D)** Correlation between testicular volumes measured by US using formula volume = L × W^2 × 0.52 and actual testicular volume.

COMMENT

The determination of the testicular volume is important in assessing pubertal development and testicular function.[2–11] A testicular volume enlargement of 4 cm^3 or greater is used as a clinical landmark for the onset of puberty.[8] In adolescents with varicocele, a testicular size discrepancy between the left and right testes has served as the main marker for surgical intervention.[6,7,9] Previous studies have suggested that a 20% to 25% volume difference is clinically significant.[7,9] In adolescence, it is important to assess age-appropriate and symmetrical testicular growth by measuring the testicular volume.[6–9] The evaluation of infertile men also includes an assessment of testicular size, which has been shown to correlate with testicular function and the semen profile.[2,3,5] Arai *et al.*[2] showed that infertile men with a sperm density of less than normal limits had a total testicular volume (sum of right and left testicular volumes) of less than 30 cm^3 as measured with the punched-out orchidometer. In the same study, patients with a total testicular volume of less than 10 cm^3 were azoospermic, and total volumes of less than 20 cm^3 were associated with severe oligozoospermia. Thus, accurate determination of the testicular volume is of great potential benefit in the evaluation of patients for a variety of disorders affecting testicular growth and function.

In the past, attempts have been made to improve the clinical accuracy of testicular volume measurement using the orchidometer, calipers, and US. Takihara *et al.*[11] reported that testicular volumes measured using the punched-out orchidometer had a strong correlation with the actual testicular volumes (r = 0.81). Other studies have demonstrated a strong linear relationship between the measurements made using an orchidometer and US. However, the orchidometer often overestimates the testicular volume, and US has become the standard method.[3,4,13,15,16,18] In addition, overestimation of the testicular size may be greater in small-volume testis.[16] Rivkees *et al.*[13] showed in animal models that the Prader orchidometer overestimates the true testicular volume by nearly 30% when the actual volume ranged from 1.0 to 15.0 cm^3, and US was more accurate and had better reproducibility than the orchidometer. The theoretical advantage of US over orchidometry is that the examiners are able to distinguish the testis from the adjacent soft tissues and epididymis and the orchidometer cannot. US has been generally accepted as the more accurate method, but debate continues.[4,13–16,19] Previous studies have shown a large variability in US measurements of the testicular volume depending on the formula used.[3,4,7,12–20] Furthermore, because previous reports showed a positive correlation between the results obtained by orchidometry and US, orchidometers are still widely used in clinical practice.[3,4,13–16,18,19] In addition, the accuracy of the testicular volume measurement by orchidometer may be more dependent on examiner experience than US.[4,14,19] A recent study showed that US volume measurements of the testes using three formulas in dogs were more accurate than the Prader and punched-out orchidometers when compared with the actual testicular volume.[12] In the same study, the most accurate formula for estimating the testicular volume by US was L × W × H × 0.71.[12] Paltiel *et al.*[12] also found that all three US formulas ($R^2 = 0.75$ to 0.9, $P < 0.001$) had stronger correlations with the actual volume than either the Prader or punched-out orchidometer ($R^2 = 0.14$, $P = 0.12$ and $R^2 = 0.38$, $P = 0.007$, respectively). However, that study was done in canine testes and did not directly compare the testicular volume measured by US and the Prader orchidometer, which is more dependent on examiner experience.[4,14,19]

Our study showed that US volume measurements were more accurate than orchidometry and that the most accurate formula was L × W × H × 0.71, as previously reported.[12] However, in our experience, the orchidometer measurements correlated with the actual testicular volume, a finding that differs from a previous report.[12] The canine testes in their study were smaller (mean volume 8.2 cm^3, range 6.6 to 12.4) than the human testes in our study (mean volume 9.3 cm^3, range 2.5 to 23.0), which may have contributed to the poor correlation between the actual volume and the orchidometer measurements. Inaccuracy of testicular volume measurement by orchidometer has been reported to be greater in small testes than in large testes, irrespective of the examiner's experience.[13,16] Moreover, our study showed that measurements using the Prader orchidometer correlated strongly with the US measurements using each of the three formulas. This is consistent with data from other reports.[3,13,16,18] We believe that orchidometry remains useful in clinical practice, especially when the absolute volume is not important. It is more important to determine the clinical implications of testicular volume measurement using the US formula L × W × H × 0.71. Knowledge of the actual testicular volume is important in adolescents with varicocele to determine the magnitude of the discrepancy in the size of the right and left testes, which may reflect testicular injury by varicocele and be an indication for varicocelectomy. The orchidometer is insufficiently precise to reliably measure such differences.[4] Therefore, we believe that US is the method of choice for measuring testicular volume in adolescents with varicocele.

In evaluating male infertility, knowledge of the absolute testicular volume is also important in the evaluation of testicular function. Two studies have shown that the testicular volume measured by the orchidometer correlates with normal testicular function.[2,5] However, few studies have evaluated the relationship between testicular function and the testicular volume measured by US.[3,21] In particular, the role of testicular volume measured using the formula L × W × H × 0.71 in a comprehensive evaluation of male infertility demands study. The main purpose of an infertility workup is to identify correctable and irreversible conditions.[22] Considering cost and convenience, a precise testicular volume measurement may not necessary in all infertile men. However, although the accuracy of orchidometry depends on examiner experience, the use of orchidometers tends to overestimate the testicular volume, especially in small testes, regardless of experience.[13,16] Additionally, orchidometry does not replace US in the evaluation of intrascrotal pathologic features, such as varicocele.

Our study had several limitations. First, all clinical material was harvested from patients with prostate cancer, who were elderly. However, previous reports have shown that the mean testicular density does not change over a wide range of testicular sizes, patient ages, or disease states.[23] Second, our study did not compare the punched-out orchidometer with water displacement and US. However, Shiraishi *et al.*[16] have shown that the punched-out orchidometer overestimates the testicular volume compared with the US formula L × W × H × 0.71 and that the testicular volume measured by punched-out orchidometer correlated strongly with that by US. Additional studies, including examination of the relationship between the testicular volume measured by US and testicular function, are necessary to establish the volumetric formula L × W × H × 0.71 as the standard method for US testicular volume measurement.

CONCLUSIONS

Testicular volume measurement by US is more accurate than by Prader orchidometry. In our study, as determined by the smallest mean difference from the actual testicular volume, the US formula L × W × H × 0.71 generated the most accurate testicular volume.

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